TACTICAL WEATHER RADARS FOR THEATER METEOROLOGICAL DATA COLLECTION AND ASSIMILATION

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ABSTRACT

The efficiency and safety of all operations conducted within the battlespace can be improved with knowledge of environmental conditions. The warfighter, whether at sea, on land, or in the air, can 1) optimize the performance of electro-magnetic and optical sensors by adjusting operational parameters, 2) select proper weapons or sensors, or 3) change the engagement scenario to take greatest advantage of the environmental conditions by knowing the propagation conditions and clutter environment which are being encountered. In addition, knowledge of wind fields can aid in a number of aspects of theater operations, including ballistic trajectory corrections and determination of path and dispersion of radioactive, chemical and biological agent weapon clouds.

Lockheed Martin Corporation has developed a signal processing technique that enables meteorological information to be collected by tactical radars. The technique allows the radar to operate using its normal tactical doctrine, and processes the return data separately to extract meteorological information. The concept has been tested through simulation and laboratory experiment, and is being used to examine the capability of the AEGIS SPY 1 B/D radar to measure meteorological information. This paper will examine the use of this signal processing technique in a number of sensors deployed throughout theater operations to extend this capability. By implementing this signal and data processing capability on a number of sensors, weather information can be collected from the edges of the theater at sea and as far as 300 miles inland.

1.0 Introduction

The efficiency and safety of all operations conducted within the battlespace can be improved with knowledge of environmental conditions. Knowing propagation conditions and the clutter environment enable the warfighter, whether at sea, on land, or in the air to aid the warfighter in decisions to: 1) optimize the performance of electro-magnetic and optical sensors by adjusting their operational parameters, 2) select proper weapons or sensors for a particular engagement, or 3) change the engagement scenario to take greatest advantage of the environmental conditions.

Knowledge of three dimensional wind fields can aid in a number of aspects of theater operations as well. Measured winds improves ballistic trajectory corrections for Naval Surface Fire Support, land based counter-battery fire and tactical ballistic missile defense. In addition, three dimensional winds information will help in the determination of path and dispersion rate of radioactive, chemical and biological agent weapon clouds.

Lockheed Martin Corporation Government Electronic Systems has developed a novel signal processing technique [1] that enables the collection of meteorological information by tactical radars. All current operational meteorological radars use uncoded waveforms for determining weather phenomena parameters, such as the three primary spectral moments. Most tactical radars use coded waveforms and pulse compression for tactical operations such as search and tracking to gain additional sensitivity and improved range resolution. Combining the two functions of tactical operations (search and track) and weather surveillance has not been appropriate until recently because of this major difference in the transmitted waveform and the signal processing and the technological barrier of the use of pulse compression in weather radars,

Meteorological sensors have not used pulse compression because of the range sidelobes generated by the pulse compression process. The technique introduced by LM GES is a doppler tolerant range sidelobe suppression (DTRSLS) technique. This technique is designed to maintain low range sidelobes over a range of doppler frequency shifts on the return pulse data. In tactical sensors, coded waveforms do not present range sidelobe problems because the requirements are not as stringent since the targets of interest are not extended over large ranges. For detection of point phenomena, peak range sidelobe (or perhaps average or RMS sidelobe) levels are of the most interest and these levels are not as sensitive to doppler shift on the return signal.

The DTRSLS technique allows the radar to operate using its normal tactical doctrine, that is, using the coded waveforms that it uses for target search and track. The DTRSLS concept has been tested through extensive simulation [2,3] and laboratory experiment [4,5]. It is currently being used to examine the capability of the AEGIS SPY 1 B/D radar to measure meteorological information at the Navy's

Combat System Engineering Development (CSED) Site in Moorestown, NJ [6].

By implementing this signal and data processing capability on sensors deployed throughout the theater, weather information can be collected from the edges of the theater at sea and as far as 300 miles inland. This assumes that the deployed forces are arriving to a theater operation from the sea, and penetrating inland. Using shipboard sensors (AN/SPY-l B/D, AN/SPN-43 AN/SPS-48, and AN/SPS-49 radars) weather information can be collected at sea, at the land-sea interface, as well as inland for approximately 50 nautical miles or more. This data can support all naval operations in the area, but in particular amphibious and landing operations, Naval Surface Fire Support, and strike operations. Once land based sensors have been deployed ashore, ground based radars such as the TPQ-37 and the Patriot radar, can be used to collect weather information approximately 150 miles inland, depending on sensor emplacement. This information can support land based operations further inland, such as forward troop movements and counter battery fire support. Finally, airborne support sensors aboard E3A AWACS aircraft can be used to CO I lect meteorological information 300 miles or more inland. Combining this weather information enables theater command to better conduct all operations in a safer more efficient manner.

The weather information from all of the tactical sensors can be used by each sensor's operator to better optimize operating parameters and better understand the clutter and propagation environment. The data from each sensor can be fed to Fleet Numerical and Meteorology and Oceanography Center (Fleet Numeric) or other forecasting organizations for use in global and local forecasting models. To reduce time latency of the data transmission networks and the time required to assimilate the data into models and run the forecasting models at the forecasting organizations, the weather data can be used onboard a sensor's platform (those with the processing power available) to provide i n situ short term local forecasts for the theater. The data collected by tactical sensors combined with the ever increasing computing power available in vector and scalar processors enables in situ forecasting within the theater, The individual sensors can use the data to:

- visualize clutter environment with a high temporal and spatial resolution, accurate clutter map to aid in waveform selection and to suppress clutter detections and tracks for improved sensor performance monitoring, optimization, and prediction;
- produce advanced weather products such as detection of hazardous weather phenomena (wind shears/shifts, storm tracking and storm structure),
- provide a three dimensional wind field maps to aid in fire control and fire support and to better understand the dispersion of chemical, biological and radioactive clouds, and
- (if sensor has sufficient sensitivity) provide detection of clear air phenomena - cloud layers and clear air wind fields.

The remainder of this paper will introduce the signal processing technique, and examine its use in a number of sensors deployed throughout the theater to extend this weather capability. In addition, preliminary hypotheses for uses i n tactical operations of the data to be collected by the tactical sensors will be presented,

2.0 *Tactical Weather Radar Concept*

The primary functions of most tactical radars deployed in a battle environment are for the surveillance and tracking of targets, either planes, missiles/shells, and surface targets (ground vehicles or surface ships). The environment in which most tactical sensors operate includes a tremendous amount of clutter and environmental returns as well as returns from these desired targets. A passing storm can significantly change the picture observed by the radar operator by presenting numerous unwanted “clutter” detections that are moving at about the velocity of the local winds or the storm movement. A chaff cloud can present a similar picture. Ducting can produce surface tracks to the operator in beam positions that would indicate these targets have altitudes of thousands of feet. Knowledge of the clutter environment and ducting conditions can change the picture displayed to a radar operator. In addition, the knowledge of the ducting and clutter can improve the performance of the sensor by allowing the operator to optimize the sensor parameters to best deal with the clutter environment at the moment, and to change the parameters as the clutter environment changes.

The challenge for the Tactical Weather Radar (TWR) Concept is to obtain as much information as possible about the weather, clutter, and propagation conditions so that the performance of the sensor and hence the warfighter can be improved. The desire is to extract this meteorological information with as little impact on the operational sensor as possible. The impact to the sensor is measured in many ways, two of the most important are: 1) additional hardware required to perform weather processing, and 2) changes in the sensor's operational doctrine, that is, altering its resource allocation budget. The goal of the TWR is minimize both of these impacts while maximizing the amount of information collected on the weather phenomena, clutter, and ducting conditions.

Ideally, the TWR will collect weather information from the same tactical dwells the radar uses to detect point targets by using an alternate processing channel. In general, the weather data collection begins with the generation of the three primary spectral moments of the phenomena. These three moments are: Reflectivity, mean doppler velocity, and doppler spectrum spread. The reflectivity is a measure of the reflected power from the scatterers within a particular resolvable range, azimuth, elevation cell; it is essentially a volumetric form of radar cross section since it is normalized by the radar parameters and the range from the radar. It is normally expressed as reflectivity factor with some adjustments made for transmit wavelength and particle scatterer type. The mean doppler velocity measure is the mean radial movement of the scatterers within the resolvable cell. The doppler spectrum spread is a measure of the variability of the doppler components that exist within the resolvable cell; it is an indication of the turbulence, bimodality or variation of the doppler.

The measurement for reflectivity does not require a multiple pulse coherent dwell, since it is a measure of the reflected power from a particular cell. To measure reflectivity, it is only required that sufficient independent samples of the weather phenomena are collected by the system to form accurate estimates of the reflectivity, if the number of independent looks can be obtained by averaging a number of range intervals and/or a number of multiple simultaneous transmissions (such as multiple transmit and receive beams or frequency channels) then a single pulse dwell can be used to determine the reflectivity. To measure the mean velocity and spectrum spread parameters a coherent multiple pulse dwell is needed. To measure these doppler characteristics, the pulse to pulse characteristics of the phenomena must be determined, such as pulse to pulse phase change which indicates doppler shift. The mean pulse to pulse phase shift is proportional to mean velocity, and the variance of this phase change is proportional to spectrum spread.

From these moments, advanced weather products can be generated describing the weather environment, its movement and evolution. These moments are used for detection of weather phenomena as well as forecasting of weather conditions. Using intelligent pattern recognition algorithms, certain patterns within the spectral moments will describe the presence of a particular type of weather phenomena, such convective storms, microbursts, and many others. In addition, the spectral moments and their change with time can be used along with other meteorological information available from other sensors aboard or satellites such as winds, temperature, barometric pressure and others to produce near and long term forecasts. Wind fields are generated using the data collected from multiple sensors (wind triangularization from radial winds) or from one sensor (existing single doppler wind retrieval algorithms).

The doctrine and mission of a sensor must be considered in the way that the TWR concept is applied. In some applications, impact on hardware (requirement to remain compact and mobile) is as important or even more important than impacting that operational doctrine. In these cases, the TWR aims to introduce little (if any at all) new hardware to perform the weather processing. Weather information can be extracted by time sharing available hardware or altering the processing in the tactical chain, without impacting the tactical performance, such that some of the signal processing for the weather information extraction can be performed in the tactical processing channel. In other cases, the impact to doctrine is important because the critical nature of the mission such as: the SPY-1 radar and providing self and area defense and for the safety of the sensor and crew, or the TPQ-37 radar where radar resources are limited for the firefinder and counter battery functions to avoid detection.

In some cases, additional meteorological information can be obtained with little additional impact to the sensor, such as small requirements on radar resources to collect additional weather information while the radar is not in a battle condition. A radar control program which is adaptable in this way can enable the system to use the amount of radar resources which are available, that is, in battle situations, minimal weather information may be collected (that available from tactical dwells), but in other conditions, an abundance of weather information can be collected because resource requirements can be reduced for some of the tactical portions of the radar's doctrine.

In some radars, multiple pulse dwells are used only in areas where clutter rejection is needed (for surface scans and where clutter exists), and this could limit the scan volume in which mean doppler and doppler spread are collected. It would be useful to extend the use of multiple pulse dwells to provide estimates of all three spectral moments throughout volume. The detailed clutter map could be used to define where multiple pulse dwells should be used, such that when a threshold is crossed a flag is set to transmit multiple pulses in a beam position. The rejection of surface clutter is important in mapping weather phenomena, the presence of surface clutter spectra in a return will produce biased estimates of the reflectivity, mean velocity and spectral spread. If radar resources are available, extra pulses could be used in the low elevation tiers to provide improved surface clutter characterization and in some cases improved surface clutter rejection, To be able to perform wind profiling and clear air observations long coherent dwells are generally used. The long coherent dwells provide signal integration (many pulses are coherently integrated) such that weak signals (like clear air) are detectable. The benefits of providing 3D wind fields and cloud layers can far outweigh the resource requirements.

The overriding goal of the TWR is provide as much weather information at as little cost as possible, where the cost is measured by dollars to place equipment for processing, and by radar resource requirements to collect weather information, Figure 1 shows a typical tactical weather radar adjunct processor. The additional processing required provides control for the weather processor side which is tied to the overall radar controller, The weather processor includes signal and data processing to calculate the three spectral moments and to provide the advanced weather products

The TWR adjunct processor will tie into the tactical radar in a number of ways. First, the received radar data will be extracted from the tactical system's receiver / signal processor by the weather signal processor (WSP). In addition, the radar control parameters will be passed to the weather system controller (WSC) by the tactical system's radar controller so that information concerning the radar operating parameters for each transmit sequence can be extracted. The WSC determines if the mode type indicates that the dwell is used for weather data collection. If so, the WSC extracts necessary information such as beam position, dwell type, operating parameters (pulsewidth, -transmit frequency, pulse repetition interval (PRI), and so on) so that the WSP can perform the proper signal processing. The WSP performs the computationally intensive signal processing such as pulse compression and doppler processing. The weather data extractor (WDE) takes the periodogram estimates or the estimates of the first lag of the autocorrelation function and calculates the spectral moments. Detailed discussion of this processing is given in [7]. The spectral moments are then passed to the weather data processor (WDP) so that weather phenomena features can be extracted by automated detection algorithms, such as gust fronts, microbursts, wind field, etc. The WDP is also used to generate short and long term in situ forecasts using both the data generated by the ownsensor and data from other tactical sensors received via the weather communication processor (WCP). The output

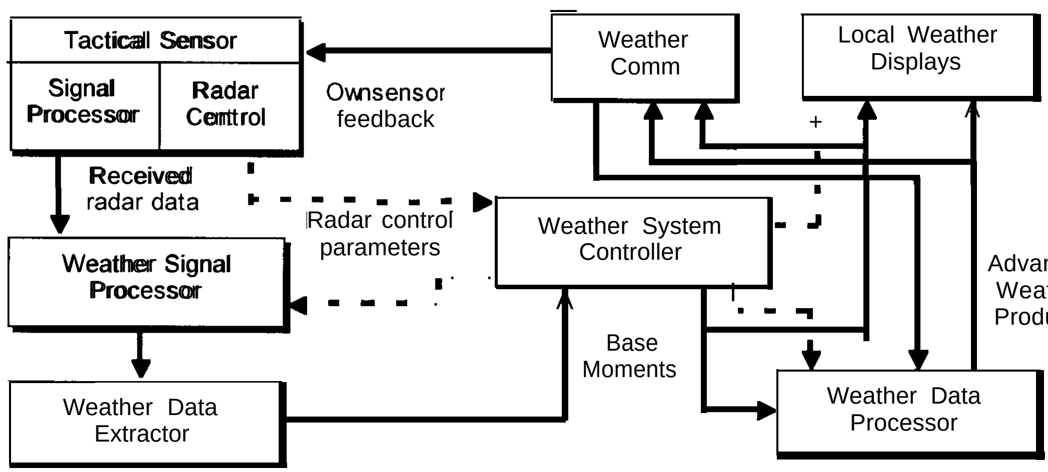

Figure 1: Tactical Weather Radar Adjunct Processor

of the WDP is formatted for presentation on the local displays as a synopsis of the weather picture, In some cases, it is desirable to view the raw spectral moments, and these will be made available for the displays as well. Finally, spectral moments and advanced weather products are sent to the WCP for formatting and message formation for transmission to other tactical radars, to theater command and/or forecasting organizations for long and short term forecasting

Minimizing the hardware impact could also minimize weather processor's achievable functionality. The trade of weather information obtained versus hardware and radar resource impact much be made on a sensor by sensor basis. The tactical mission and hardware configuration of each sensor will change the trades sufficiently such that a solution for one sensor may not easily extend to others.

3.0 Weather Surv. and Pulse Compression

Weather phenomena are random processes, the spectral moments of weather phenomena are also random. In measuring the primary spectral moments, a sensor must obtain multiple independent looks of a resolvable cell so that the variability in the measurement can be reduced and accurate measures of reflectivity, mean velocity and spectrum width can be obtained. The number of looks required is dependent on the parameters of the radar (pulse repetition frequency, transmit frequency, sensitivity parameters which determine signal to noise ratio - gain, transmit power, losses) and the assumed properties of the weather phenomena (spectral spread, coherence time), as well as the required accuracy of the spectral moments. A typical value for the number of independent samples for an S-Band radar is 100. The multiple independent looks at a resolvable cell can be obtained in any number of ways, including: multiple transmit pulses, multiple simultaneous transmit/receive channels, range sample to range sample, and multiple scans.

All current operational meteorological radars use uncoded waveforms for determining weather phenomena parameters. Tactical radars, on the other hand, use coded waveforms and pulse compression for tactical operations such as search and tracking to gain additional sensitivity and improved range resolution, Combining tactical operations and weather surveillance has not been appropriate until recently because of this major difference in the transmitted waveform and the signal processing and the technological barrier of the use of pulse compression in weather radars.

Meteorological sensors have not used pulse compression because of range sidelobes which are a result of pulse compression. Range sidelobes arise from the distributed nature of the pulse compressed signal, Range sidelobes are energy received at the desired sampling time but from other ranges than that of the desired range interval When a coded waveform is pulse compressed, what results is a function of time whose range extent covers more than the compressed pulsewidth (the inverse of the transmit signal's bandwidth). Figure 2 shows a typical pulse compression function, its time extent is twice the transmit pulsewidth, its range resolution is equal to the width of the mainlobe portion which is approximately the inverse of the transmit signal's bandwidth. The distributed nature of weather requires extremely low range sidelobes to avoid corruption, since the weather extent is greater than the compressed pulse length.

In tactical sensors, coded waveforms do not present range sidelobe corruption problems since the targets of interest are not extended over large ranges. In addition, for detection of point phenomena, peak range sidelobe level (PSL) (or perhaps average or RMS sidelobe levels - RSL) levels are of the most interest and these levels are not as sensitive to doppler shift on the return signal. For extended phenomena such as weather, the figure of merit for the range sidelobes is integrated sidelobe level (ISL). ISL is the measure of the total sidelobe energy divided by the total mainlobe energy. ISL is an acceptable measure of sidelobe performance for distributed phenomena since it measures the amount of energy received from all range sidelobes compared to the mainlobe return just as would be expected from a n extended weather return. The smaller the ISL, PSL, or RSL (greater negative values in dB), the better the sidelobe performance.

Many methods exist for reducing range sidelobes but these techniques are very sensitive to doppler. Without a priori knowledge of the doppler environment, the range sidelobes that are achieved through these suppression techniques may not be sufficient to avoid corruption from range sidelobes. The DTRSLS technique is designed to maintain significant range sidelobe suppression over a range of doppler frequency shifts on the return pulse data. Figure 3 shows the improved integrated sidelobe levels that are achieved with the DTRSLS versus those with non doppler

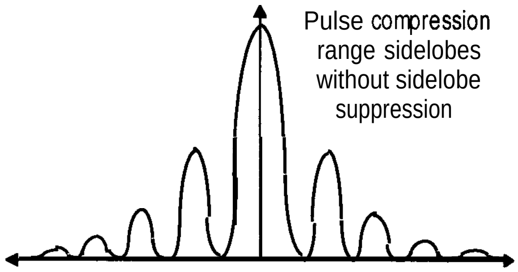

Figure 2: Pulse compression function

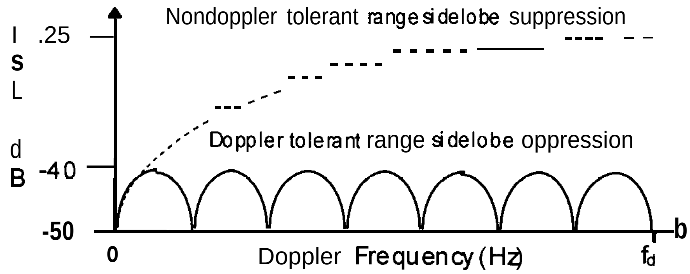

Figure 3: Integrated sidelobe levels versus doppler shift

tolerant range sidelobe suppression. The DTRSLS technique allows a radar performing tactical and weather surveillance to operate using its normal tactical doctrine, that is, using the coded waveforms that it uses for target search and track. The meteorological information is extracted by processing the return data separately from the normal tactical signal and data processing using an optimized range sidelobe suppression processing channel.

The DTRSLS concept has been tested through simulation and laboratory experiment. An extensive simulation effort analyzed its performance in accurately mapping weather phenomena, including range sidelobe level performance in the presence of certain weather phenomena and system characteristics, which includes the fluctuating nature of the weather phenomena and the transmitter and receiver characteristics of the radar. Laboratory tests were conducted using research weather radars to collect time series data transmitted virtually simultaneously using "normal" weather radar waveforms (uncoded) and processing, and using coded waveforms and pulse compression with DTRSLS. The data were then processed off-line to determine the weather parameters of the volume scanned. The Tactical Weather Radar concept is being used to examine the capability of the SPY 1 B/D radar to measure meteorological information at the Navy's Combat System Engineering Development (CSED) Site in Moorestown, NJ.

Pulse compression for weather surveillance provides significant benefits. The two major improvements are: 1) increased sensitivity to detect weaker weather phenomena, and 2) data collection time reductions [8]. The sensitivity increase is achieved by transmitting more average power on the weather phenomena (increasing the average power by increasing the pulsewidth). The increase in sensitivity through pulse compression is then equivalent to the time bandwidth product of the coded waveform (when compared to a system that has the same range resolution without using pulse compression and the same peak transmit power). The data collection time reductions are achieved through a higher transmit signal bandwidth which provides improved range resolution (smaller resolvable range cells), which are averaged as independent samples of the return signal to achieve accurate spectral moment estimates. Pulse compression can be used to change the way that radars perform weather surveillance. Figure 4 depicts current weather radar surveillance technology, and weather surveillance technology employing pulse compression. Present weather surveillance technology uses a mechanically scanned reflector antenna with long multiple pulse coherent dwells using uncoded transmit pulse over a single transmit / receive channel.

Many tactical radars have properties that provide significant capability for weather surveillance. As explained above, pulse compression provides significant performance enhancements in the way of increased sensitivity and reduced data collection times. Since most tactical sensors employ transmit waveforms that are of much higher bandwidth than a typical weather radar these advantages are easily employed in a TWR.

Also, many tactical sensors are electronically scanned phased arrays (scanning either 1 D or 2D), and this property of tactical sensors also provides significant benefits to weather surveillance. In general, an electronically scanned phased array can scan a volume faster than a mechanically scanned array because of mechanical scan speed limitations that are applicable to electronic scanning. In addition, a phased array can employ time division multiplexing of beams to collect data faster. Time division multiplexing collects data from multiple beam positions at a singe time on one transmit channel, by transmitting and receiving at each beam position for only a limited amount of time during each pulse [9]. Another advantage of electronic scanning is the inertia-less beam pointing. Scan modulation introduces a bias error into the spectral width by amplitude modulating the return signals because the point on the beam at which the

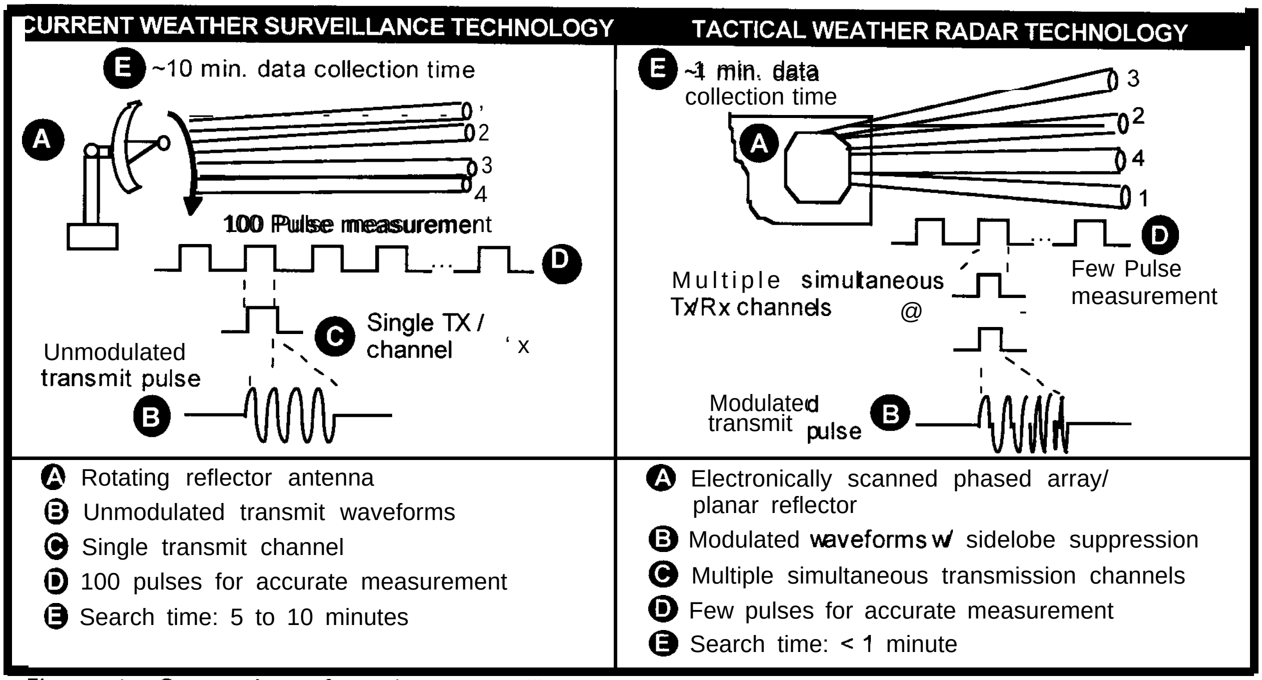

Figure 4: Comparison of weather surveillance radar strategies

return is measured changes during the dwell as a result of the mechanical scanning. Using a two dimensional electronically scanned phased array eliminates the scan modulation that is inherent in a mechanically scanned system, a one dimensional electronic scan will reduce but not eliminate scan modulation since it still mechanically scans in one dimension.

Mechanically scanned systems use fixed radar resource scheduling, and do not normally stray from this fixed scan sequence. Phased arrays, however, can dynamically allocate resources to various functions to enable multiple prioritized functions to be built into the same sensor, In addition, resource allocation can be optimized to provide full functionality for each function based on it's radar resource requirements. The radar can allocate resources to the function with the highest priority requiring resources at that time, and can accommodate new functions like dedicated weather dwells which provide significantly improved functionality.

Many tactical radars utilize multiple simultaneous transmit / receive channels which enables the radar to collect data from multiple operating frequencies, beam positions, polarizations, etc, at one time, For weather surveillance, these channels can be used to collect the independent samples that are required to reduce the variance of the spectral moment estimates as discussed previously,

In most tactical sensors operating doctrine, there are multiple radar scans that comprise the radar's full scan capabilities. These scans can be single pulse horizon search and volume search scans, multiple pulse horizon and volume search scans, single pulse and multiple pulse track scans, and many others, These individual scans may have properties which can be exploited in the collection of weather data. In addition, the multifunction scans allow new scans to be added that may allow improved weather data collection but also have some benefits for tactical operation, such as a pulsed doppler dwell on the horizon for a sensor that does not currently employ such a scan. This dwell provides capability for both weather and tactical operations by improving the surface clutter spectrum characterization.

4.0 Theater Met. Data Collection Concept

The TWR concept enables Theaterwide weather data collection and assimilation. This concept calls for a multitude of tactical sensors deployed throughout the theater to collect weather information in the TWR fashion, and to share this information and also to provide the information to Fleet Numeric or other forecasting organizations. The weather data, basic spectral moments, advanced weather products and forecasts - including short term in situ forecasts, can be used at each sensor for performance optimization and at theater command and throughout the theater for planning, execution and evaluation of all operations. Figure 5 shows a concept for a theatervvide, TWR based, weather data collection and assimilation concept.

The theaterwide data collection concept allows weather information to be collected at sea, at the land-sea interface, and inland as much as 300 miles or more to the target area using multiple deployed tactical sensors aboard ship, deployed inland, and airborne. The amount and type of weather information collected will depend on the deployment of each of the sensors in the theater, and the tactical weather radar capability built into each of the sensors used to collect the data.

The inherent line of sight for each type of sensor (shipborne, land based, or airborne) limits the weather data collection capability. For shipborne sensor weather capabilities using the TWR concept, an inherent line of sight range capability is on the order of 50 - 100 Miles inland depending on the deployment of the ship in relation to the shore. A shipborne weather capability will have a range extent of approximately 150 miles. The shipborne weather capability will be useful in collecting data for the detection of storms, the mapping three dimensional winds, and the detection of cloud layers. For land based sensor weather capabilities using the TWR concept, an inherent line of sight range capability is on the order of 100 to 150 miles inland depending on the deployment of the land based sensor in relation to the shore and the sensitivity of the sensor. A land based weather capability will have a range extent of approximately 50 to 150 miles, The land based weather capability will be useful in collecting data for the detection of storms, and the mapping of three dimensional winds. For airborne sensor weather capabilities using the TWR concept, an inherent line of sight range capability is on the order of 150 to 300 miles inland depending on the flight path of the airborne sensor in relation to the shore and the sensitivity of the sensor. An airborne weather capability will have a range extent of approximately 100 to 200 miles. The airborne weather capability will be useful in collecting data for the detection of storms. The detection range extent for each type of system will be dependent on the sensitivity of the system (transmit power, antenna gains, losses, etc.). The sensitivity of the systems varies greatly from sensor to sensor, such the weather sensing capabilities will also vary greatly. Each of the three types of sensor will be able to provide the three primary spectral moments along with any of the advanced weather products that are generated for each application.

A variety of sensors can be used in the TWR concept. Table 1 shows properties and functionality for a number of radars. The three current generation radars used by the National Weather Service (NWS) and the Federal Aviation Administration (FAA) for weather surveillance are included: Next Generation Doppler Weather Radar (NEXRAD) - NWS, Terminal Doppler Weather Radar (TDWR) - FAA, Airport Surveillance Radar -9 (ASR-9) - FAA. Also included in the table are list of tactical sensors that could be used with a TWR adjunct processor to provide weather data collection capabilities. Included are shipborne sensors (AN/SPY-I, AN/SPN-43, AN/SPS-48, AN/SPS-49), ground based sensors (TPQ-37 and Patriot Radar), and an airborne sensor (AWACS radar). In each case, the tactical radars selected share some of the aspects of the three operational weather sensors. In general, all of the tactical sensors use pulse compression (some also use uncoded waveforms) and achieve fine range resolution and increased sensitivity as a result. The range resolution is in general smaller than that of the three operational weather sensors. The tactical sensors have sensitivities that vary widely as a

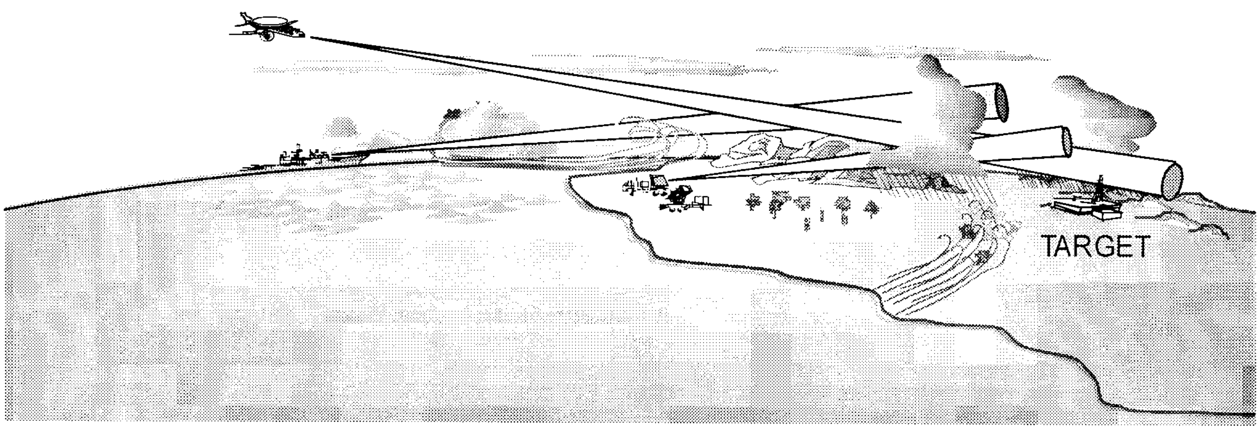

Figure 5: Theaterwide meteorological data collection through data fusion from multiple sensors

Table 1: Tactical weather radar candidate sensor comparison with weather radars

Radar / Property	NEXRAD	TDWR	ASR-9	SPY-1	TPQ-37
Frequency	2.7 - 3.0	C-band	2.7-2.9	S-band	S-band
Power	750 kW	250kW	1 MW	High	Low
PRF	1 kHz nom,	1 kHz nom,	1 kHz nom,	can achieve	can achieve
Pulse Type	Uncoded	uncoded	uncoded	coded	uncoded / coded
Dwell type	Multiple pulse	Multiple pulse	Multiple pulse	single / Multiple pulse	Multiple pulse
Range resolution	0,25 and 1.0 km	0,25 and 1.0 km	150 m	can achieve	can achieve
Beam type	10 pencil	1" pencil	Fan	Pencil	Pencil
Antenna type	Rotating reflector	Rotating reflector	Rotating reflector	Stationary Phased array	Trainable phased array
Function	Weather surveillance	Hazardous Weather surveillance / Aviation weather	Air Traffic Control / Weather Surveillance	Volume & horizon search/track, Missile commun. & fire control	Firefinder / Counter battery
Radar / Property	**AWACS**	**AN/SPN -43**	**AN/SPS- 48**	**AN/SPS- 49**	**Patriot**
Frequency	S Band	S Band	S band	L band	C-Band
Power	Low / medium	~850 kW	High	High	High
PRF	can achieve	can achieve	can achieve	can achieve	can achieve
Pulse Type	uncoded / coded	uncoded / coded	coded	coded	coded
Dwell type	Multiple pulse	single / Multiple pulse	single / Multiple pulse	single / Multiple pulse	single / Multiple pulse
Range resolution	can achieve m '(Maritime Mode"	can achieve	can achieve	can achieve	can achieve
Beam type	Fan	Pencil	Pencil	Fan	Pencil
Antenna type	Rotating phased array	Rotating reflector	Rotating planar array	Rotating reflector	Trainable phased array
Function	Airborne surveillance	Aircraft approach	Surveillance & tracking - long range & horizon	Long Range Air Surveillance and Track	AAW / Firecontrol

result of their different operating frequencies, beamwidths, peak transmit powers, pulsewidths, etc. but in most cases, they provide sufficient sensitivity to match or exceed at least one of the three sensors and can provide weather surveillance over a limited range extent.

5.0 *Benefits to the Warfighter*

The TWR provides many benefits to the warfighter deployed throughout the theater.

For forecasting and modeling of weather phenomena and its movement, the TWR weather data provides improved accuracy, resolution, and timeliness of weather forecasting to warfighters. The TWR weather data collection is an enabling technology for in-situ forecasting models, allowing the warfighter to have direct access to forecasting and modeling data within the theater. The TWR allows rapid and accurate local nowcasts (short term forecasts). It provides high resolution local measurements to warfighters throughout the theater. Improved forecasting capabilities supports safer, more efficient littoral, amphibious and expeditionary operations, improved force mobility, and improved long term and global forecasts from Fleet Numeric and other forecasting operations.

For aircraft operations, the nowcasts provided by the TWR generate weather information up to and over the target area which support safer, more efficient air strikes, helo operations and aircraft carrier operations. The nowcasts and detection of weather phenomena by the TWR provide the warfighter with winds, wind shear, gust fronts, as well as cloud tops and bottoms, and storm extent and structure.

The TWR weather data can improve force self defense and area anti-air warfare (AAW) for each sensor. The sensitivity of the sensors can be improved in two ways. First, the radar system can lower its detection thresholds (added sensitivity by detecting smaller targets) in the presence of clutter, which would inherently generate more clutter detections that can be screened by the detailed clutter map. Second, the waveform selection process uses the detailed clutter map to choose the proper waveform parameters (number of pulses, pulse repetition frequency, etc.) based in the reflectivity, mean velocity and spectrum spread of the clutter in the region of the transmission.

The radar system will have better radar resource management and improved awareness through the clutter map. Clutter tracks can be reduced, eliminating resources required to "track clutter". In addition, waveform selection can be made more efficiently eliminating the need to revisit beam positions with multiple dwells with varied parameters to achieve the necessary clutter visibility. The clutter map can also be used in conjunction with detection reports to infer propagation conditions. The detection results can confirm if surface tracks appear at higher elevations meaning that a surface duct exists. This can substantiate or refute the predicted propagation conditions and their homogeneity, particularly between propagation condition measurements, The improved situational awareness provided by the weather data can be useful in capability assessment for tactical decision aids (TDAs) for a sensor. The SPY -1 system has a TDA called the AEGIS Tactical Assessment Capability (ATAC) that provides insight into the AEGIS Weapons System's performance against a threat given the current environmental conditions and system status.

For Tactical Ballistic Missile (TBM) missions, TWR provides improved battlespace awareness through: assessment of cloud cover (by cloud layer detection), detection of three dimensional wind fields and spectral characterization of the environment. The cloud cover assessment and storm structure supports the seeker selection for the defensive missile, to assure that IR seekers are not blind during an engagement in clouds or storms. The wind field maps aid in the prediction of the dispersion of the cloud produced by the warhead within the TBM. The winds fields and spectral characterization aid in the analysis of the environment within a TBM complex for kill assessment and perhaps debris discrimination. Wind fields and spectral characterization can aid in the engagement process if enough time is available and resources are limited, the engagement decision can be influenced by the predicted impact point and the anticipated dispersion cloud movement in relation to forces and civilians.

In Chemical, Biological and Radioactive scenarios (CBR), wind fields can be used i n much the same way it is used for TBM. Dispersion models can be driven with measured 3D winds rather than point measurements and modeled winds, Impact zones can be determined using the winds information. Also, the TWR wind data can improve: the engagement decisions, force mobility in the impact area, and evacuation of forces and civilians from impact areas and areas of anticipated dispersion cloud contamination.

The winds information aids all types of fire support with improved accuracy of weapon delivery from measured accurate and timely 3D winds not point measurements or modeled winds, both at the gun and over the target area. Naval Surface Fire Support and Army ground based counterbattery fire will both be supported with accurate ballistic corrections, Also, the clutter maps will aid the fire support i n identification of chaff for improved tracking.

6.0 *Summary*

A concept for the collection of weather information from tactical sensors has been presented. This concept has wide applicability for sensors deployed throughout the battlespace. The data collected from the various sensors can be fused to yield a picture of the propagation and clutter conditions within the theater. In addition, 3D wind fields and other advanced weather products such as storm tracks and storm structure can be generated and made available

The weather data has wide reaching benefits for the warfighter. Beginning with improved performance of each sensor, as well as aiding in the capability assessment of each sensor. In addition, the data aids in more efficient, safer operations throughout the battlespace, from amphibious and landing operations, to expeditionary operations and force mobility to air operations.

7.0 *References*

1, H. Urkowitz and N. J. Bucci, "Doppler Tolerant Range Sidelobe Suppression in Pulse Compression Meteorological Radar", Proceedings Int'l Geoscience & Remote Sensing Symposium, Houston, TX, May 26-29, 1992, Volume Number pages 206-208.

2. N. J. Bucci and H. Urkowitz, "Testing of Doppler Tolerant Range Sidelobe Suppression in Pulse Compression Meteorological Radar", Proceedings 1993 IEEE National Radar Conference, Boston, MA, April 20-22, 1993, pages 206-211,

3. R. L. Nevin, J. M. Ashe, N. J. Bucci, H. Urkowitz and J. D. Nespor, "Range Sidelobe Suppression of Expanded / Compressed Pulses with Droop", Proceedings IEEE National Radar Conference, Atlanta, GA, March 29-31, 1994,

4. N. Bucci, J. Nespor, H. Urkowitz, D. Mokry, R. Brown, and W. Baldygo, "An Experiment with an S-Band Radar Using Pulse Compression and Range Sidelobe Suppression for Meteorological Measurements", Proceedings of 1994 IEEE National Radar Conference, Atlanta, GA, March 29-31, 1994 pgs 35-40,

5. N. J. Bucci, H. S. Owen, C. M Hawes, K. Woodward, 'Validation of Pulse Compression Techniques for Meteorological Functions", Contract Final Report for DTFA01-95-C-00021, June 1, 1996.

6. H. S. Owen, H. Urkowitz, N. J. Bucci, J. V. Melody, R. McLean, "Tactical Weather Radar Experiment For a Shipborne Radar", Proceedings of Battlespace Atmospherics Conference; Naval Command, Control and Ocean Surveillance Center, RDT&E Division; San Diego, CA; December 3-5, 1996

7. R. Doviak and D. Zrnic, Doppler Radar and Weather Obser-_, New York: Academic Press, Inc., 1993.

8. R. J. Keeler and C. L. Frush, "Rapid Scan Doppler Radar Development Considerations, Part II: Technology Assessment", 21st Conference on Radar Meteorology, AMS, Edmonton, Canada, 1983, pp 3.1-3.5,

9. S. L. Katz, J. D. Nespor, "Advantages of Agile Beam Radar for Meteorological Surveillance", Proceedings of the 26th Int'l Conference on Radar Meteorology, May 24-28, 1993, Norman, OK, pp 396-398.